CHAPTER 5. CALIBRATION OF THE SNOW ACCUMULATION AND ABLATION MODEL

5.1 INTRODUCTION

In the application of a conceptual hydrologic model for river forecasting, the calibration process is extremely important. The calibration procedure used must not only result in realistic parameter values which produce reasonable simulation results, but also must be efficient so that a large number of river basins can be calibrated in a reasonable time. The procedure recommended is a combination of trial-and-error calibration and automatic parameter optimization. Trial-and-error calibration involves subjective manual adjustments to parameters based on an analysis of previous simulation results. In automatic parameter optimization, the computer adjusts parameters in a semi-random manner based on changes in the value of a single numerical evaluation criterion. The automatic technique used in the NWSRFS is the direct-search optimization technique, Pattern Search. A complete description of the Pattern Search algorithm is given by Monro (1971). The evaluation criterion which has been adopted is the sum of the squares of the errors between simulated and observed mean daily streamflow. Chapter 7 of HYDRO-14 describes the computational features and basic options of the computer program (NWSRFS3) which performs Pattern Search optimization.

This chapter outlines and discusses a recommended calibration procedure for river basins where the snow accumulation and ablation model is used. Only the snow model parameters are discussed in detail. The user should refer to chapter 7 of HYDRO-14 for suggestions regarding the determination of initial soil-moisture accounting and channel routing parameters and the optimization of those parameters.

In addition to calibrating the snow, soil-moisture accounting, and channel routing models on the basis of hydrograph simulation, the snow model can be calibrated by comparing the computed and observed water-equivalent of the snowpack. However, it is generally not feasible to calibrate the snow model using water-equivalent data because frequent representative water-equivalent measurements are not available for the large majority of watersheds.

5.2 OUTLINE OF STEPS IN THE RECOMMENDED CALIBRATION PROCEDURE

There are five basic steps in the recommended calibration procedure for the snow accumulation and ablation model. This section outlines the steps and the following sections discuss each step in detail.

a. Select initial values for each of the snow parameters (snow parameters are listed in section 3.4). Also select initial values for the soil-moisture accounting and channel routing parameters (see chapter 7 of HYDRO-14).

b. Simulate the entire calibration data period using the verification program. Check for periods when the form of the precipitation is in error, i.e., snow when rain actually occurred and vice versa. Adjust those periods that are determined to be in error. Also check for and correct any large data errors that can be substantiated.

Large errors should not be present if the data were properly checked for consistency at each stage of data preparation.

c. Perform trial-and-error calibration of the model parameters using the verification program (NWSRFS4).

d. Perform Pattern Search optimization on those parameters for which satisfactory values were not determined by trial-and-error calibration. The optimization program (NWSRFS3) is used for Pattern Search optimization.

e. Analyze calibration results. Repeat steps c and d if necessary.

5.3 INITIAL VALUES OF THE PARAMETERS FOR THE SNOW ACCUMULATION AND ABLATION MODEL

This section presents guidelines for determining initial values for each of the parameters included in the snow accumulation and ablation model. The definition of each parameter is listed in section 3.4. If other nearby watersheds have been calibrated, the parameter values from these watersheds should also be helpful in determining initial values. However, as mentioned in the following guidelines, certain snow parameters are influenced significantly by geographical conditions. Thus, values of these parameters from nearby watersheds should only be used to determine initial values if geographical conditions between the watershed being calibrated and the nearby watersheds are similar.

a. PXTEMP. Model calibration studies to date indicate that 33°F provides for the best delineation of rain from snow, i.e., 33°F and below, precipitation is snow - above 33°F, precipitation is rain. Some other investigators have found that 34°F or even 35°F gave the best results.

b. SCF. The gage catch deficiency correction factor during snowfall varies considerably depending on gage exposure, especially the effects of exposure on the wind velocity at the gage. Another important consideration is whether the gage has a windshield. Figure 5-1 shows typical gage catch deficiency correction factors during snowfall for shielded and unshielded gages as a function of wind speed. Although wind speed data at each precipitation gage are generally not available, Fig. 5-1 should be helpful in determining the initial value of SCF if some information on wind speeds over the area and on gage exposures is available.

c. MBASE. It is recommended that 32°F be used as the base temperature for melt computations during non-rain periods. In some studies other base temperatures have been used in an attempt to get a better linear relationship between snowmelt and air temperature. Results from the watersheds calibrated using this snow model indicate that 32°F is a completely adequate base temperature.

d. UADJ. Sublimation - condensation measurements during the Snow Investigations (1955) at the Central Sierra Snow Laboratory, and at the NOAA-ARS cooperative snow research station near Danville, Vermont resulted in nearly identical wind functions. The wind function computed from these measurements is:

$$f(u) = 0.006 \cdot u, \tag{5.1}$$

where: u is wind movement at 1/2 meter above the snow surface in miles, and
f(u) has units of inches/(in. Hg) ~~miles).~~

Thus, the initial value of UADJ would be 0.006 multiplied by the average six-hour wind movement in miles at the 1/2 meter level during rain on snow events.

e. MFMAX and MFMIN. As noted in Chapter 3, melt factors change as the relationship varies between air temperature and the meteorological variables affecting heat exchange. Therefore, climatological differences and differences in physiographic variables such as forest cover, slope, and aspect which affect radiation exchange and wind movement will cause one area to have a different melt factor than another area. With all other variables held constant, the following statements are generally true:

1. South facing slopes would have a higher melt factor than north facing slopes.

2. Areas where windy conditions prevail generally have a higher melt factor than areas where calm conditions prevail (however, under conditions of low humidity, sensible heat gain could be balanced or exceeded by latent heat loss).

3. The melt factor increases as forest cover decreases.

Most of the other variables are so interrelated that it is impossible to change one and hold all the others constant (e.g., solar radiation cannot be increased significantly without a decrease in atmospheric longwave radiation). Thus, it is difficult to make general statements about the effect of these variables on the melt factor.

A good initial value of MFMAX and MFMIN can be computed for a few areas based on snowpack water-equivalent and temperature data. When there is no snowfall during a snowmelt period, the amount of snowmelt can be approximated by the difference in water-equivalent measurements. The slope of a plot of the summation of snowmelt versus the summation of six-hourly air temperatures above MBASE is the melt factor for that snowmelt period. (It should be noted that when the area has less than 100 percent areal snow cover that the snowmelt values should be adjusted to represent the condition of 100 percent areal snow cover since the melt factor used in the model represents melt over the entire area.) A number of such plots from snowmelt periods occurring at different times during the year and from several snow seasons should define good initial values for

MFMAX and MFMIN. The main problem with using this method to estimate melt factors is that representative water-equivalent measurements, taken at frequent intervals, are made on only a very few areas.

Based on results from the areas tested on the model to date, forest cover seems to be the major factor affecting the variability of melt factors from one area to another area. Figures 5-2 and 5-3 show plots of maximum and minimum melt factors versus forest cover for the areas on which the model has been tested. These plots should be helpful in providing a reasonable initial value for parameters MFMAX and MFMIN when representative water-equivalent data are not available.

f. <u>TIPM</u>. The antecedent temperature index (ATI) is an index to the temperature of the surface layer of the snowpack, as discussed in section 3.3.2.2. The parameter TIPM indicates the thickness of the layer being considered. Values of TIPM less than 0.1 would give significant weight to temperatures over the past week or more and would thus indicate a deeper layer than TIPM values greater than 0.5 which would essentially only give weight to temperatures during the past day. A brief examination of snowpack temperature and air temperature data from the NOAA-ARS cooperative snow research site indicates that TIPM = 0.5 would correspond to a three- to six-inch surface layer while TIPM = 0.2 would correspond to approximately the top 12 inches of the snowpack.

It is felt that eventually the value of TIPM can be standardized. However, a complete analysis of the effect of different values of TIPM has not been completed. TIPM = 0.5 has given reasonable results on the watersheds tested though there is some indication that a lower value may be more appropriate.

g. <u>NMF</u>. The value of the negative melt factor is a function of the climatic conditions that occur over the snowpack when the air temperature is below 32°F. The value of NMF is also influenced by the density of the surface layer of the snowpack since the thermal conductivity of snow is a function of density. In addition, the value of the negative melt factor is dependent on the value of TIPM since TIPM controls the magnitude of ATI (ATI is an important quantity in Eq. 3.15 for calculating the change in heat storage during periods when the air temperature is below 32°F). Because of the interrelationship between NMF and TIPM it is recommended that a reasonable value of TIPM be established based on the guidelines suggested previously for parameter TIPM. Then, during model calibration only NMF would be allowed to vary. It should be noted that the optimization program does not allow TIPM to vary. Only parameter NMF can be included in automatic optimization.

The value of the maximum negative melt factor (NMF) has varied from 0.003 to 0.007 for the watersheds tested to date. An initial value of 0.005 should be satisfactory.

h. <u>Areal depletion curve</u>. There are a number of ways to determine the areal depletion curve for a given area. Several methods are listed below in order of the accuracy of the final product.

1. Determine the areal extent of snow cover over a number of years from aerial photographs and the areal water-equivalent from ground surveys on a number of days during the snowmelt period. An analysis of such measurements will result in the areal depletion curve. Except for a few watersheds, such information is not available nor is it generally practicable to obtain such measurements.

2. Measure the ablation of the snowpack by periodically making water-equivalent measurements at a representative site within each reasonably homogeneous geographical subarea. The subareas would be selected on the basis of elevation, vegetal cover, and aspect. As each subarea becomes bare, a point on the areal depletion curve could be established since the number of bare areas would be known and also the water-equivalent of those areas, where snow remains, would be known. Five to ten subareas should be adequate to obtain a reasonable estimate of the areal depletion curve.

3. In many areas the data necessary to use method number 2 for computing the areal depletion curve are not available and it would not be practicable to obtain water-equivalent data for each homogeneous subarea. However, in many areas some water-equivalent data are available. An approach similar to method 2 could be used in such areas by using the available water-equivalent data and by subjectively estimating accumulation and melt rates for the other subareas.

If data are not available to compute the shape of the areal depletion curve, then the shape of the curve must be arbitrarily selected. The same shaped areal depletion curve has been used for all of the watersheds tested to date. This curve (shown in Fig. 3-3) was originally computed for the Central Sierra Snow Laboratory using water-equivalent data from snow courses and areal snow cover determined from aerial photographs. Analysis of similar data indicates that the shape of the areal depletion curve for the Upper Columbia Snow Laboratory is essentially the same as that for Central Sierra. The same curve was also used for the Sleepers River watersheds and the Passumpsic River areas for which similar data were not available. Model calibration did not indicate that the shape of the areal depletion curve should be altered. All of these watersheds are similar with respect to elevation range and cover. In addition, the same curve was used successfully for the Rock River above Rock Rapids, Iowa. This watershed is an open agricultural area with little variation in elevation where during spring melt the period from complete snow cover to bare ground is normally only a few days. In this case, it was difficult to determine the shape of the areal depletion curve accurately by hydrograph simulation. While the same shaped curve gave good results on these watersheds, different shaped curves would probably be required on areas with different elevation ranges and cover configurations.

i. SI. The previously mentioned methods of determining the areal depletion curve would also indicate the areal water-equivalent above which 100 percent snow cover always exists. If one of these methods is not used, the following guidelines can be used to select an initial value for parameter SI.

1. If the area is very heterogeneous in regard to slope, aspect, and vegetal cover, then the initial value of SI should be about the same as the maximum water-equivalent that occurs. This is due to the fact that in very heterogeneous areas there are usually places where very little snow accumulates. Thus, these places will become bare soon after snowmelt begins.

2. If the area is more homogeneous, then the area would remain at 100 percent cover during the early portion of the snowmelt season, thus SI would be lower than the maximum water-equivalent that occurs. In the extreme case of a perfectly homogeneous area, such as a point study area, SI would be equal to zero.

j. PLWHC. Most measurements on "ripe" snow have indicated liquid-water retention capacities of less than 10 percent and in most cases on the order of two to five percent. Slush layers may be formed at the snow-soil interface or in conjunction with ice layers within the snowpack. These slush layers can hold a considerable amount of liquid-water. While slush layers form in deep snowpacks, their relative effect on the total liquid-water retained is usually small. However, in shallow snowpacks slush layers will increase the percent liquid-water holding capacity significantly. It is recommended that the initial value of PLWHC should be in the range 0.02 to 0.05 for areas which normally have deep snowpacks (approximately greater than 10 inches water-equivalent). The initial value of PLWHC should be greater for areas with normally shallow snowpacks, with a value of 0.25 not being unreasonable for an area such as the northcentral region of the United States.

k. DAYGM. The following guidelines, based on model testing to date, should be sufficient to obtain a reasonable estimate of the daily amount of melt at the snow-soil interface.

TABLE 5-1.--Guidelines for determining parameter DAYGM.

DAYGM (inches)	Climatic Conditions
0.0	Long cold winters (many days with air temperatures below 0°F), and shallow snowpacks
0.01	Long cold winters, and deep snowpacks
0.02	Moderate winters (temperatures above 0°F during most of the snow season), and deep snowpacks

1. EFC. A reasonable value for EFC can be obtained from a knowledge of the percent of the area covered by forests (usually available from topographic maps with a woodland overprint) and the type of forests. EFC is not an important parameter in most areas, but does influence the volume of snowmelt runoff from forested watersheds. The influence is greatest on forest watersheds where snowmelt occurs in late spring when evapotranspiration demand is increasing.

5.4 ADJUSTMENT OF AIR TEMPERATURE DATA WHEN FORM OF PRECIPITATION IS IN ERROR

The determination of model parameters can be severely affected when there are large errors in the data used for calibration. Errors in determining the form of precipitation can be classified under data errors. Ideally, the basic input data to the model would include the form of the precipitation. However, information on the form of precipitation for each six-hour period is not available. Therefore, since such input data are not available, it is necessary for the model to estimate the form of precipitation. As discussed in Chapter 3, the estimation of the form of precipitation is based on air temperature. The form of precipitation can be correctly estimated in most cases using air temperatures measured near the ground surface. However, ground level air temperatures are obviously not a perfect index to the form of precipitation, thus there will be times when the model estimation of the form of precipitation is in error. These cases should be corrected after the initial run of the verification program so that further parameter calibration is not affected.

An examination of the simulated versus observed discharge plot will indicate those periods during which an error in determining the form of precipitation might have a significant effect on model results (e.g., if the observed hydrograph shows a sizable response and the simulated hydrograph shows no response, this could be a case of rain occurring when the model determined that it was snowing). The next step is to examine the daily snow summary printout to determine if precipitation did occur, since the discrepancy could have been the result of an error in estimating the amount of snowmelt. In many cases, a significant deviation between model response and observed response is sufficient to verify that the form of the precipitation is in error. However, especially when the deviation is not great enough to make the cause obvious, it becomes necessary to examine other available data to determine if the form of precipitation is actually in error. Two types of data which are helpful in determining whether the form of precipitation is in error and which are usually readily available are:

a. Hourly or three hourly air temperature data from NWS first order stations or other recording temperature stations. Experience has shown that in most cases when the form of precipitation was in error, it was because maximum-minimum air temperature data were not sufficient to describe the daily variation in air temperature. The assumption of the maximum air temperature occurring in the afternoon and the minimum occurring near sunrise is more likely to be in error on days with precipitation than on days with no precipitation. For example, most of the periods when the form of precipitation was in error for the Passumpsic basin were nighttime periods when the model estimated that it was snowing when actually rain was occurring. An examination of hourly temperature records revealed that in almost all cases the nighttime temperatures had remained well above 33°F. Minimum temperatures below 33°F had occurred during daylight hours on the previous day and/or the following day.

b. Snowfall and snow on the ground data from daily observation stations. Program PRELIM2 (see section 2.4.2) will list snowfall and snow on the ground data for all daily observation stations that are selected for use in the basin analysis. This information is helpful in determining the actual form of the precipitation.

After determining which periods the form of precipitation is in error, the next step is to correct those periods. In some cases, it may be possible to correct most of the periods by changing the parameter PXTEMP. To correct the remaining periods it is necessary to change the six-hourly mean areal air temperature. On the watersheds tested to date, the number of periods for which air temperature was changed varied from zero on the Rock River at Rock Rapids, Iowa to 39 over an eight-year period on the Passumpsic River. Appendix G lists a computer program which will transfer data in NWSRFS standard tape format from one tape to another tape and change air temperature data for selected periods in the process.

5.5 TRIAL-AND-ERROR CALIBRATION

Trial-and-error calibration involves subjective manual adjustments to model parameters based on specific characteristics of previous simulation results. To perform trial-and-error calibration in an effective manner it is necessary to know: 1) which displays of simulation results should be examined and what to look for, 2) how different types of deviations between simulated and observed conditions indicate which parameters need to be changed, and 3) how large an adjustment should be made to a parameter to correct an observed deficiency in simulation results. Obviously, experience with using the model is very helpful in trial-and-error calibration. Even though there is no real substitute for experience, hopefully the following suggestions will improve the effectiveness of trial-and-error calibration for those who are using the model for the first time.

a. Which displays of simulation results to examine and what to look for. The most all inclusive display of simulation results is the plot of the simulated and observed mean daily discharge. This is the primary display to be analyzed. Displays such as the daily summary of snowpack conditions and the monthly summary of soil-moisture accounting volumes and variables are helpful in interpreting deviations between simulated and observed mean daily discharge. Portions of the statistical summary table should also be examined during trial-and-error calibration. The monthly, annual, and flow-interval percent bias columns are the most important statistics to examine in terms of determining simulation errors. In addition, RMS error, correlation coefficient, and the intercept and slope of the best fit linear regression line between simulated and observed daily discharge, give an indication as to whether a trial-and-error run was an improvement over previous runs.

The important thing to look for in examining these displays is consistent errors. Examples of consistent errors are:

1. The volume of flow during spring melt is always low.

2. Discharge is normally too low during the early portion of the spring melt period and too high during the later portion.

3. Mid-winter snowmelt rises are too high.

4. Low flows are simulated too high and high flows are too low.

5. Monthly flow volume is low in the spring, slightly high in the summer and winter, and quite high during the autumn.

6. Runoff volume is over-estimated during periods when soil-moisture is relatively low and under-estimated during periods when soil-moisture is high.

7. Peak discharge is low, but the recession limb of the storm hydrograph is high.

When the deviations between simulated and observed discharge are reasonably random, then parameter calibration is complete.

b. How to identify consistent deviations with model parameters. Once consistent model errors are identified, the next step is to determine which model parameter or parameters need to be changed to correct the error. Two suggestions which may be helpful in this regard are:

1. Try to relate the deviation in the hydrograph to the most likely physical cause. Then look at the structure of the model to determine which parameter or parameters control the physical process that is in error. For example, if the volume of spring runoff is low, it may be because the water-equivalent of the snowpack prior to melt is too low. An examination of the model structure reveals that the water-equivalent of the snowpack prior to spring melt is primarily a function of the gage catch deficiency correction factor and melt during the accumulation season. If there are no significant melt periods during the winter or if winter melt periods are simulated with reasonable accuracy, then parameter SCF is probably in error. On the other hand, if there are a number of mid-winter melt periods, the majority of which are simulated much too high, then MFMIN and MFMAX may be all or partly to blame for the error in the volume of spring snowmelt runoff.

2. Experiment with the model by varying the value of a single parameter and noting the effect on model response. Such experiments will indicate under what conditions each parameter affects model response and also the characteristics of the change in response. Figures 5-4, 5-5, and 5-6 show the effect of three of the most important snow parameters on model response. It should be noted that each of these parameters has a unique effect.

The complicating factor in determining which parameter values should be changed is that in most cases not one, but a number of parameters are in error simultaneously. In these situations, it is usually not possible to identify all the parameters that should be changed. It is recommended that the parameter which is felt to have the largest effect on the simulation error be changed first. A hydrologist with experience in using a model may change a large number of parameters on a single trial-and-error run. However, it is recommended for the beginner that the number of changes be kept small. Only the value of one parameter should be changed for each major simulation error that is identified (e.g., spring volume is too high or melt occurs too early in the spring).

In addition to experimenting with model parameters to determine their effect on hydrograph response, the sensitivity mode of the optimization program can be used to study the magnitude of the effect a given parameter has on simulation results. The sensitivity mode of the optimization program shows the effect that various values of different model parameters have on the evaluation criterion (sum of squares of the difference between simulated and observed mean daily discharge). This effect can be illustrated by a sensitivity plot. A sensitivity plot is made by establishing a parameter set and varying a single parameter holding all other parameters constant. Figures 5-7, 5-8, and 5-9 show sensitivity plots for the six major snow parameters on the Passumpsic River. Two different data periods were analyzed to show that the effect of parameter variation and the "optimum" magnitude of parameters can be different for different data periods. Several points should be noted regarding these plots:

1. The value of one parameter, especially an important parameter, can affect the sensitivity plot of other parameters. For example, the water-equivalent of the snowpack was underestimated for the earlier period (12/64 - 5/68). To compensate for this volume deficiency, the evaluation criterion could be improved by retarding melt during the winter, thus holding the water in the snowpack until spring. This is why low values of parameter MFMIN and high values of parameter NMF caused an improvement in the evaluation criterion. This helps show why an examination of the plots of mean daily discharge is essential in trial-and-error calibration. The output of the 12/64 - 5/68 sensitivity run might suggest that SCF, MFMIN, and NMF should be changed when in reality the values of MFMIN and NMF are quite reasonable and only SCF is in error.

2. The snow correction factor, SCF, and the non-rain melt factor are the most sensitive and the most important snow parameters. SCF is the only snow parameter which has a significant effect on the volume of runoff from the snowpack (EFC affects volume to a small degree). All the other snow parameters affect the timing of the snowpack runoff. Of these, the non-rain melt factor is the most important. MFMAX is generally more important than MFMIN since most of the snowpack runoff occurs after March 21 in areas where there is a significant snowmelt contribution to runoff.

3. Some parameters are more sensitive to changes in one direction than to changes in the other direction. This can be noted in the sensitivity plot for parameter SI.

c. <u>How to determine the magnitude by which to change parameter values.</u> There are two basic methods of determining how the magnitude of a change in the value of a parameter will affect simulation results. These have been mentioned previously since the methods also aid in determining which parameters should be changed. The two methods are: 1) experimentation with the model parameters to determine their effect on hydrograph response, and 2) evaluation of sensitivity plots. Experience has shown that in the early stages of trial-and-error calibration reasonably large changes in parameter values are better than small changes. The determination of the optimum value of a parameter seems easier if the optimum value is bracketed than if the optimum value is approached from one direction.

Trial-and-error calibration should be applied to the entire data period used for the calibration analysis. Initially, one or two water years may be sufficient to determine parameter changes. However, as the simulation results begin to look reasonable, the entire data period should be included in the analysis. Trial-and-error calibration should be continued until the purpose for which trial-and-error calibration is being used is accomplished. This purpose may be to obtain reasonable initial parameter values for Pattern Search optimization or the purpose may be the complete calibration of the watershed. Sections 5.6 and 5.7 include a discussion of the uses of trial-and-error calibration in conjunction with Pattern Search optimization for determining model parameter values for a given watershed.

5.6 PATTERN SEARCH OPTIMIZATION

5.6.1 INTRODUCTION

It is obvious that a conceptual hydrologic model can be calibrated solely by a trial-and-error procedure. However, there are two disadvantages of trial-and-error calibration: 1) the effectiveness of the procedure is largely determined by the amount of experience that the person who is performing the calibration has with the model, and 2) the number of man-hours needed to analyze simulation results to determine parameter changes is generally large. An automatic optimization technique would overcome these disadvantages. However, besides requiring relatively large amounts of computer time as compared to trial-and-error calibration, automatic optimization techniques have disadvantages of their own. These include:

a. Parameter adjustments are based on a single criterion of model performance.

b. A sub-optimum set of parameter values can be calculated as a result of poorly selected starting values.

c. Interrelationships between model parameters can cause: 1) the solution to converge slowly to the optimum, 2) parameter values to be distorted, and 3) optimum parameter combinations, but unrealistic values of individual parameters to be calculated.

In addition, because of the computer time necessary, there is usually a practical limit on the period that can be analyzed by automatic optimization techniques. The procedure recommended for use with the NWSRFS uses trial-and-error in the initial stages of calibration to minimize most of the disadvantages of automatic optimization. Automatic optimization using the direct search technique, Pattern Search, is then used to minimize the disadvantages of trial-and-error calibration.

5.6.2 MINIMIZING THE DISADVANTAGES OF PATTERN SEARCH

The following disadvantages of Pattern Search optimization can be minimized by the proper use of trial-and-error calibration.

a. <u>Poor selection of starting values</u>. The main reason for using trial-and-error calibration prior to Pattern Search optimization is to insure a reasonable set of starting parameter values. Trial-and-error calibration should always be continued until a set of parameter values is obtained which will produce a simulated mean daily discharge plot which resembles the actual mean daily discharge plot.

b. <u>Effect of interrelationships between parameters</u>. There are several difficulties that can arise during Pattern Search optimization because of interrelationships between parameters. These difficulties include:

    1. When one parameter is not at its optimum value, other parameter values can be distorted. This is especially true when the parameter, which is not at the optimum, is a very important parameter. Table 5-2 illustrates how Pattern Search optimization can distort parameter values. The final parameter values based on eight years of data are: SCF = 1.1, MFMAX = 0.022, and NMF = 0.003. When SCF is set to 1.4 and not included in the optimization, the values of MFMAX and NMF are distorted. When all three parameters are optimized, the value of NMF is still distorted because NMF has only a minor effect on the evaluation criterion compared to SCF and MFMAX.

2. The solution may converge slowly to the optimum. This effect is also illustrated by Table 5-2. The value of SCF converges slowly to the optimum when all three parameters are included, partly because of the interrelationship between SCF and MFMAX. The value of MFMAX increases at first to compensate for the high starting value of SCF. As SCF approaches its optimum value, the value of MFMAX reverses direction and returns to its optimum. The value of SCF converges more rapidly to the optimum when only SCF is included in the optimization.

3. If several parameters have much the same effect upon the transformation of the input data into the output hydrograph; Pattern Search will seek the optimum parameter combination. This can lead to satisfactory model performance, but physically unrealistic parameter values. Examples of this case are the parameters CC and LIRC6, which control the volume and timing of interflow, and the time-delay histogram and the parameter KS1, which determine the channel response function in the NWSRFS (these parameters are defined in chapter 4 and chapter 5 of HYDRO-14). A large volume of interflow and significant attenuation within the channel system have a similar effect on the output hydrograph.

Table 5-2.--Effect of including different parameter combinations in Pattern Search optimization. Passumpsic River, 12/69 - 6/71.

Case	Run No.	Parameter Value			Evaluation Criterion x 10^8
		SCF	MFMAX	NMF	
All three parameters included	1	1.40	0.022	0.0030	2.20
	15	1.27	0.028	0.0017	.87
	30	1.02	0.027	0.0004	.63
	47	1.11	0.022	0.0009	.34
MFMAX and NMF optimized	1	1.40	0.022	0.0030	2.20
	31		0.026	0.0003	1.54
Only SCF optimized	1	1.40	0.022	0.0030	2.20
	13	1.11			.38

To avoid some of the difficulties caused by interrelationships between parameters, the number of parameters which are included in Pattern Search optimization should be kept to a minimum. Especially those parameters which have only a minor effect on the evaluation criterion should not be included in Pattern Search optimization. To keep the number of parameters which are included in Pattern Search optimization to a minimum, the value of as many parameters as possible should be determined in advance. Parameter values can be determined by:

1. An analysis of the observed discharge hydrograph. Soil-moisture accounting parameters LKK6, A, EPXM, LIRC6, and KGS, plus the

channel response function can generally be determined by hydrograph analysis.

2. The value of a number of parameters can be determined adequately by physical considerations. This includes snow parameters PXTEMP, MBASE, TIPM, EFC, and the shape of the areal depletion curve plus soil-moisture accounting parameters K1, GAGEPE, K24EL, and SRC1.

3. The value of parameters which have a minor effect on the evaluation criterion can be determined through trial-and-error calibration by examining only those periods when the parameter is important. The evaluation criteria used in Pattern Search optimization is affected mainly by parameters which control high flow periods and parameters which control the majority of the events.

A number of snow model parameters have been purposely excluded from Pattern Search optimization because of the difficulties caused by interrelationships between parameters. The parameters PXTEMP, MBASE, TIPM, EFC, and the shape of the areal depletion curve must be determined prior to Pattern Search optimization. In addition, adequate final values for parameters NMF, PLWHC, and DAYGM should be able to be obtained from trial-and-error calibration. This leaves five snow model parameters which could be included in Pattern Search optimization. These parameters are SCF, MFMAX, MFMIN, UADJ, and SI.

c. Analysis of a limited data period. In order to get realistic and stable parameter values, the data period being analyzed by Pattern Search optimization should contain a variety of typical hydrologic conditions which can occur over the watershed (e.g., periods of high soil-moisture and periods of low soil-moisture, high flows and low flows, relatively large snowpacks and relatively small snowpacks, mid-winter melt events and rain on snow events, as well as spring snowmelt). In addition, there should be a reasonably large number of events so that plus-and-minus data errors would tend to balance each other. Also in regard to the snow model, it is important to include many days of snowmelt so that the melt factors will not be based on a limited number of climatic conditions. The optimization computer program (NWSRFS) limits the period that can be analyzed by Pattern Search optimization to 50 months. A 50-month period can generally be found which contains sufficient hydrologic variety plus reasonably unbiased data errors and climatic conditions. Trial-and-error calibration should be quite helpful in the selection of a data period for Pattern Search optimization. This is true, since many of the factors which determine period selection are examined closely when analyzing the hydrograph to determine parameter changes during trial-and-error calibration.

It should be noted that in some watersheds it is impossible to find a 50-month period which has enough hydrologic variety plus unbiased data errors and climatic conditions. An example of such a watershed is the Rock River at Rock Rapids, Iowa. There were four significant snowmelt rises, each of short duration, in the ten-year period being analyzed. In addition, there were two significant rises caused by rain. Only three of the significant rises in the hydrograph occurred in any 50-month period. In this case, Pattern Search optimization was not an effective tool for parameter calibration, thus the calibration was performed solely by trial-and-error.

5.6.3 ADDITIONAL COMMENTS OF THE USE OF PATTERN SEARCH OPTIMIZATION

The previous section discussed several things that could be done to improve the effectiveness of Pattern Search optimization for use in the calibration of a conceptual hydrologic model. The three major recommendations were:

a. Reasonable starting values should be determined for all model parameters that are to be included in Pattern Search optimization.

b. The number of parameters included in Pattern Search optimization should be kept to a minimum. Parameters which have a small effect on the evaluation criterion should not be included. As many parameters as possible should be determined by physical considerations, by hydrograph analysis, and by trial-and-error calibration before using Pattern Search optimization.

c. The data period selected for analysis with Pattern Search optimization should contain as much hydrologic variety as possible. The period should also contain reasonably unbiased data errors and climatic conditions.

Several other comments regarding the use of Pattern Search optimization and the optimization computer program (NWSRFS3) which may be helpful are:

a. The optimization program contains a provision that selected periods can be removed from the calculation of the evaluation criterion. Thus, the parameter values will be based only on the remaining periods. This provision can be used to an advantage in some watersheds where snow is included. Soil-moisture accounting and channel routing parameters could first be optimized by removing all periods when snow is a factor. Then the snow parameters could be optimized by using only those periods when snow influenced the hydrograph. Obviously, this procedure is of no value in areas where snow is a factor in almost all significant rises of the hydrograph. The procedure of optimizing soil-moisture accounting and channel routing parameters on one run and snow parameters on the next run is ideally suited to the transitional zones where snowmelt is not the major source of runoff.

b. The input for the optimization program specifies that upper and lower constraints be provided for each parameter. The purpose of having constraints is to insure that physically unrealistic parameter values are not calculated by Pattern Search optimization.

c. The purpose of Pattern Search optimization is to assist in the determination of realistic parameter values which produce reasonable simulation results. These parameter values will then be used to predict hydrographs in the future. It is not the purpose of Pattern Search optimization to make slight adjustments to parameter values in order to get the best possible RMS error. The future is not going to be exactly like the past. Figs. 5-7, 5-8, and 5-9 indicate that the analysis of different periods will give different parameter values. Therefore, there is no reason to expect that after reasonable simulation results have been obtained that further slight adjustments to parameter values will improve future streamflow forecasts.

d. It is suggested that the maximum number of runs (MAXN, see card 21 of input summary - appendix E) of the optimization program be set equal to approximately ten times the number of parameters that are included in Pattern Search optimization.

e. The "best" parameter values as determined by Pattern Search optimization are not necessarily those which give the lowest value of the evaluation criterion. The mean discharge column also should be examined. In some cases, a large flow bias can exist when the evaluation criterion is at its lowest value. A large bias is not desirable.

5.7 ANALYSIS OF THE CALIBRATION RESULTS

After finishing the initial trial-and-error calibration and the first use of Pattern Search optimization, the results need to be analyzed to determine if parameter calibration is complete or if further trial-and-error calibration and possibly further Pattern Search optimization are necessary. The first step is to run the entire data period, using the verification program, with the parameter changes determined by Pattern Search optimization. If an analysis of the estimated and observed mean daily flow plots and an examination of the statistical summary indicates that the errors seem to be reasonably random, then the calibration is complete. If consistent errors still remain, then further trial-and-error calibration and possibly further Pattern Search optimization are needed to try to eliminate or reduce these errors.

Listed below are some possible reasons for consistent errors still remaining after the initial trial-and-error calibration and the first use of Pattern Search optimization:

a. Important model parameter or parameters may not have been corrected properly during trial-and-error calibration nor included in Pattern Search optimization.

b. The period used for Pattern Search optimization may not be representative of the entire data period.

c. The channel response function may not be adequate to describe properly the response of the channel over the entire range of discharge. Variable Lag and/or variable K may need to be included.

d. There may be deficiencies in the conceptual model. For example, the effect of frozen ground and other temperature related phenomena which affect the movement and retention of water in soil are not included in the soil-moisture accounting model. Consistent errors will result when phenomena occur which are not included in the conceptual model or which are not modeled satisfactorily. Further calibration will not correct these deficiencies.

5.8 OTHER CALIBRATION CONSIDERATIONS

5.8.1 USE OF ELEVATION ZONES

The computation of snowmelt and the form of precipitation is based on mean areal temperature in the snow accumulation and ablation model. Snowmelt is either assumed to be occurring over the entire area or no snowmelt is assumed to be occurring anywhere in the area. Also, either all the precipitation is assumed to be rain or it is all assumed to be snow. In addition, as the areal extent of the snowpack is depleted in a mountainous area, the mean areal temperature is no longer the same as the mean temperature over the snow covered area. The use of mean areal temperature to estimate snowmelt and the form of precipitation can result in errors. Simulation errors in the computation of snowmelt will occur primarily during the early portion of the snowmelt season when melt occurs only at low elevations and late in the snowmelt season when only the high elevations are covered with snow. The estimation of the form of precipitation will cause simulation errors during periods when rain is occurring at low elevations and snow is occurring at high elevations. Such simulation errors will be unimportant when the elevation range of the area is small, but increase in importance as the elevation range increases. To reduce these simulation errors, the elevation range needs to be reduced. The elevation range can be reduced by dividing the watershed into subareas based on elevation (elevation zones). Based on the watersheds tested to date with the snow model, it is not possible to give specific guidelines as to when elevation zones should be used. For the Passumpsic River, the RMS error was improved by about six percent and the correlation coefficient by about one percent when two elevation zones were used. The Passumpsic River has an elevation range of 1500 feet over 90 percent of the area (discounting the lower and upper five percent of the area - elevation range is 2900 feet for the entire area). The same parameter values that were used for the total area were used for each subarea except for SI (SI varied between areas since the amount of water equivalent varies). None of the other watersheds were modeled using elevation zones.

In addition to improving simulation results because of more representative air temperature data, improvements also may be possible through the use of different parameter values for each elevation zone. Since physiographic and climatic conditions vary with elevation, it would seem logical that model parameters also should vary. Simulation results can be improved by varying parameter values between elevation zones. However, unless care is exercised, the improvements may be at the expense of unrealistic parameter values. As mentioned previously, a slight improvement in simulation results does not insure that the future can be predicted with greater accuracy. Several suggestions which may be helpful if parameter values are varied between elevation zones are:

a. In a large watershed with several elevation zones, it may be possible that there are some small gaged areas which lie within a single elevation zone. Calibration of these small areas will provide a good estimate of the parameter values for the elevation zone, as long as physiographic conditions are similar between the small gaged area and the rest of the elevation zone.

b. The simulated snowpack water-equivalent for each elevation zone should be compared with available water-equivalent measurements to insure that the simulation of the snowpack is reasonable.

c. Differences in parameter values between elevation zones should be physically realistic.

5.8.2 EFFECT OF THE PRECIPITATION NETWORK ON THE SNOW CORRECTION FACTOR

In many cases, the precipitation network used in model calibration is different from the network used for operational river forecasting. Many stations are included in the published climatological network which do not report to a River Forecast Center. On the other hand, stations report to a River Forecast Center, but their precipitation data are not published as part of the climatological network. Results to date indicate that the most stable and realistic parameter values can be obtained when as much data as possible are included in the parameter calibration analysis. Because of data retrieval problems, it is generally not feasible to include stations which are not part of the published climatological network in the calibration analysis. Parameter values obtained during the calibration analysis are applicable to the operational data network as long as there is no bias between the data values obtained from the two networks. If there is no bias, the differences in simulation results from the two networks will be random.

The snow correction factor is an indication of the catch deficiencies during snowfall of the individual gages which makeup the precipitation data network. Thus, the snow correction factor for one precipitation data network probably will be different than that for another. Two possible methods for determining the snow correction factor for the operational precipitation network are:

a. The snow correction factor, SCF, could be determined for the operational precipitation network by trial-and-error calibration and Pattern Search optimization if all the stations included in the operational network are also part of the climatological network. In this case, mean areal precipitation would be recomputed using only those stations which are in the operational network.

b. The snow correction factor for the operational precipitation network (SCF_H) could be computed as

$$SCF_H = R_{C/H} \cdot SCF_C \quad , \tag{5.2}$$

where: $R_{C/H}$ is the ratio of mean areal precipitation during snowfall of the climatological network compared to the operational network, and

SCF_C is the snow correction factor for the climatological precipitation network.

In this case, all the stations in the operational hydrologic network do not have to be part of the climatological network.

The number of stations actually reporting during any time period would not affect the value of the snow correction factor. Missing precipitation data would be estimated from those stations which do report based on predetermined inter-station relationships. These relationships might include storm type, form of precipitation, and wind speed.

It should be noted that in addition to adjusting the snow correction factor, network effects on rainfall amounts and air temperature also must be considered so that the operational data network will not bias the simulation results.

References:

Monro, John C., "Direct Search Optimization in Mathematical Modeling and a Watershed Model Application," NOAA Technical Memorandum NWS HYDRO-12, U. S. Department of Commerce, Washington, D.C., April 1971, 52 pp.

Larson, Lee W., "An Application of the Dual-Gage Approach for Calculating "True" Solid Precipitation," National Weather Service, NOAA, Silver Spring, Md., presented at the 53rd Annual Meeting of the American Geophysical Union, Washington, D.C., April 17-21, 1972, 18 pp.

"Lysimeter Studies of Snow Melt," Snow Investigations Research Note No. 25, U. S. Army Corps of Engineers, North Pacific Division, Portland, Oregon, 1955, 41 pp.

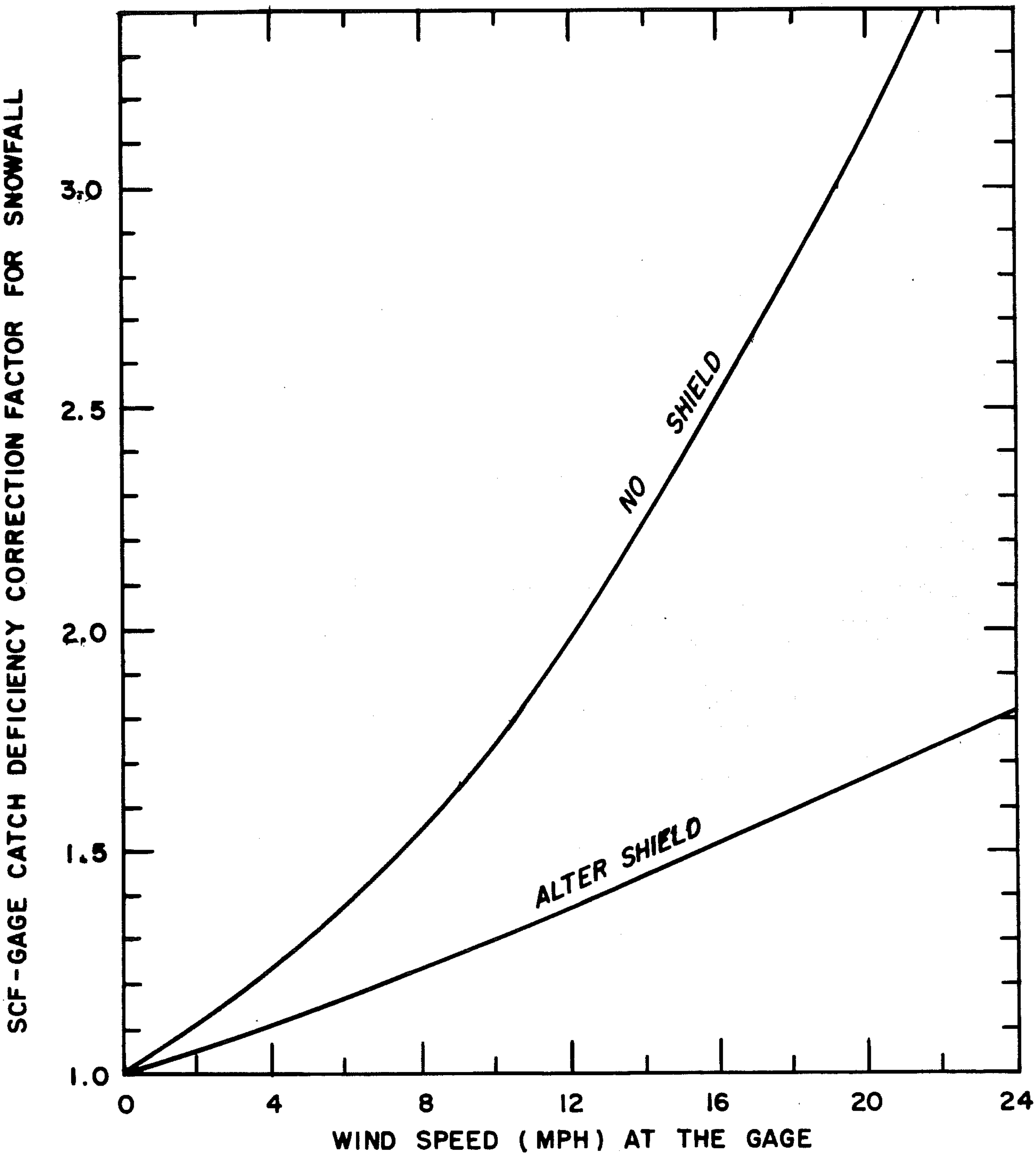

Figure 5-1. Typical gage catch deficiency correction factors during snowfall for shielded and unshielded gages (Larson 1972).

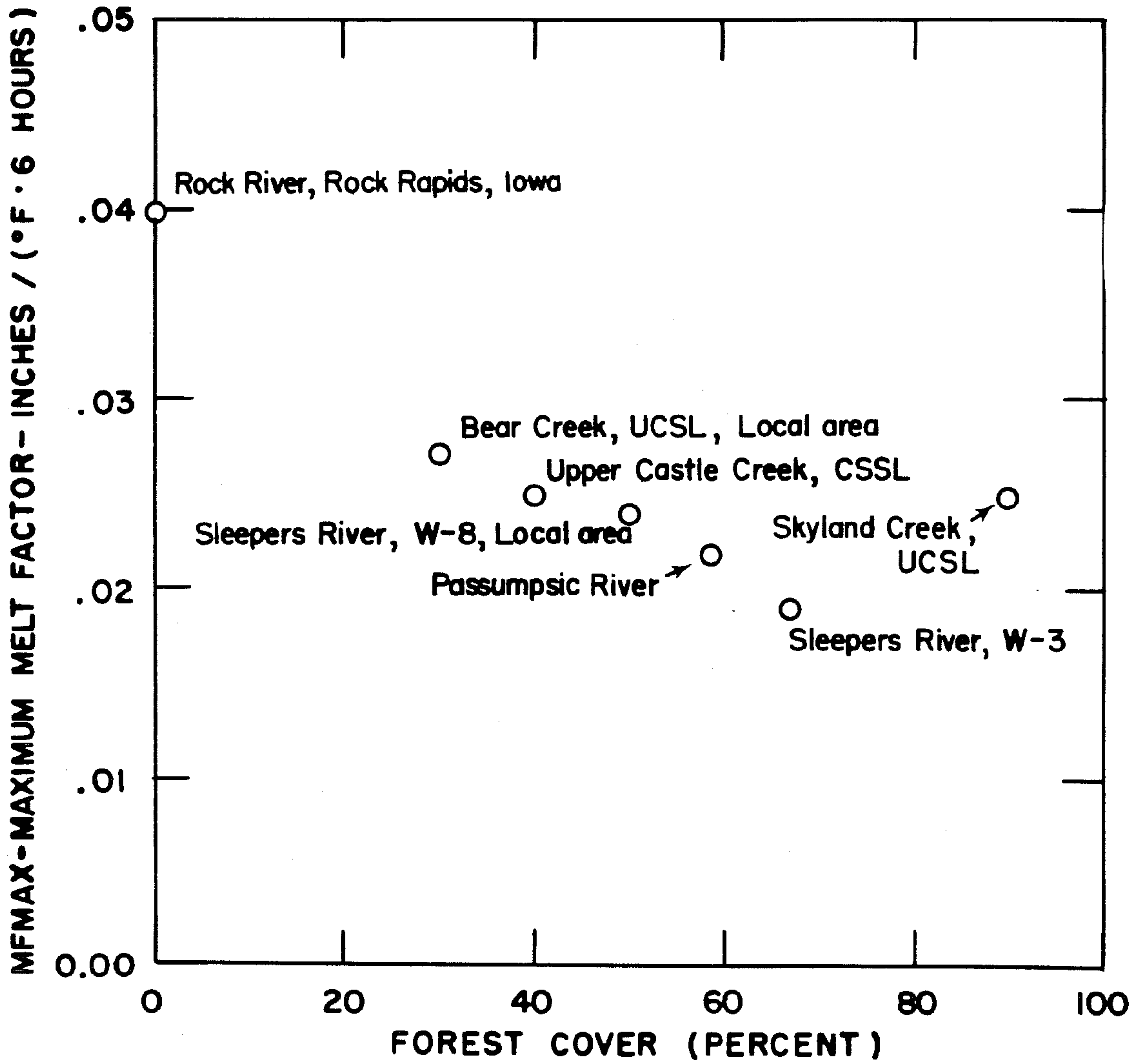

Figure 5-2. Maximum melt factor versus forest cover for areas tested on snow model.

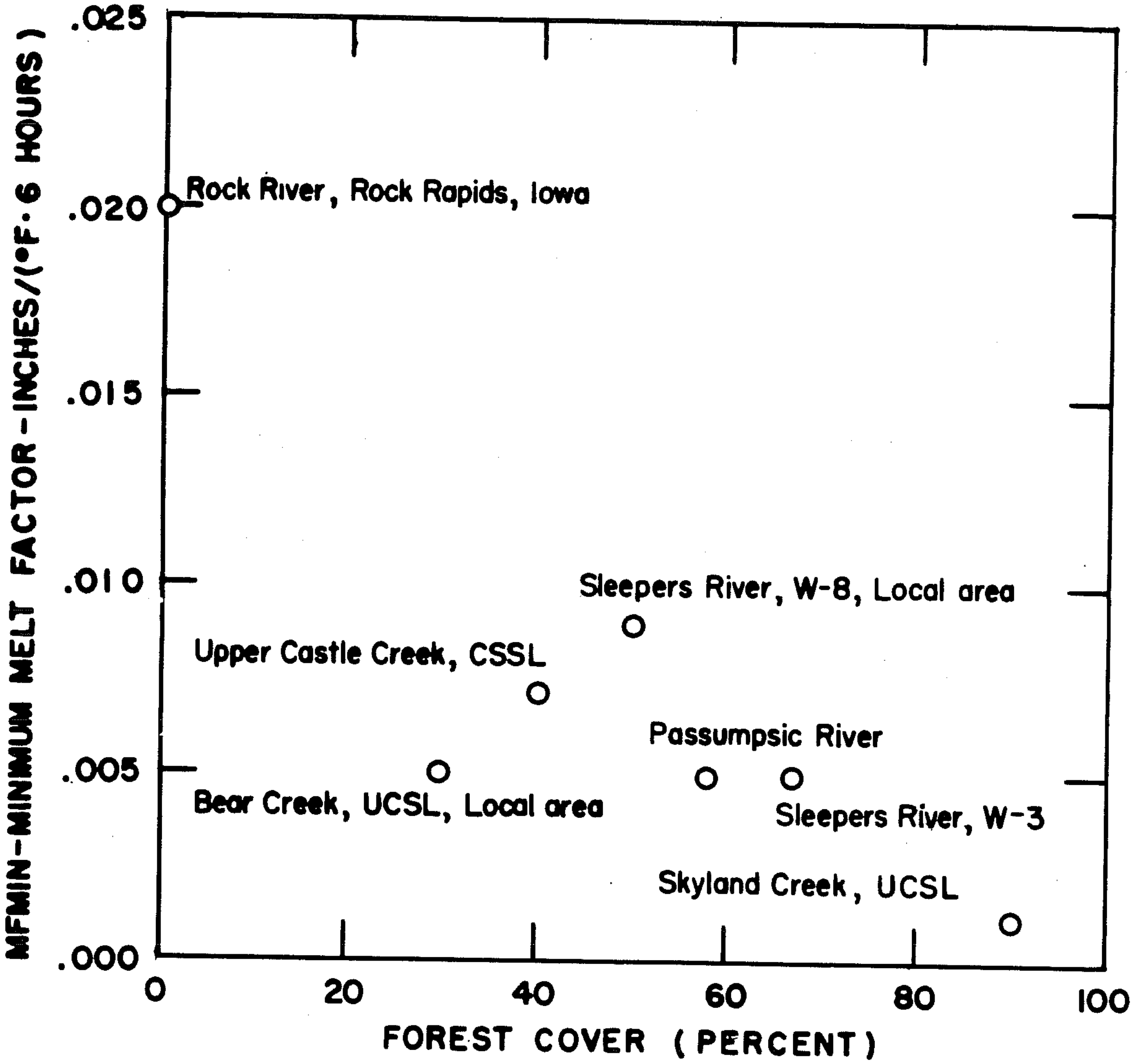

Figure 5-3. Minimum melt factor versus forest cover for areas tested on snow model.

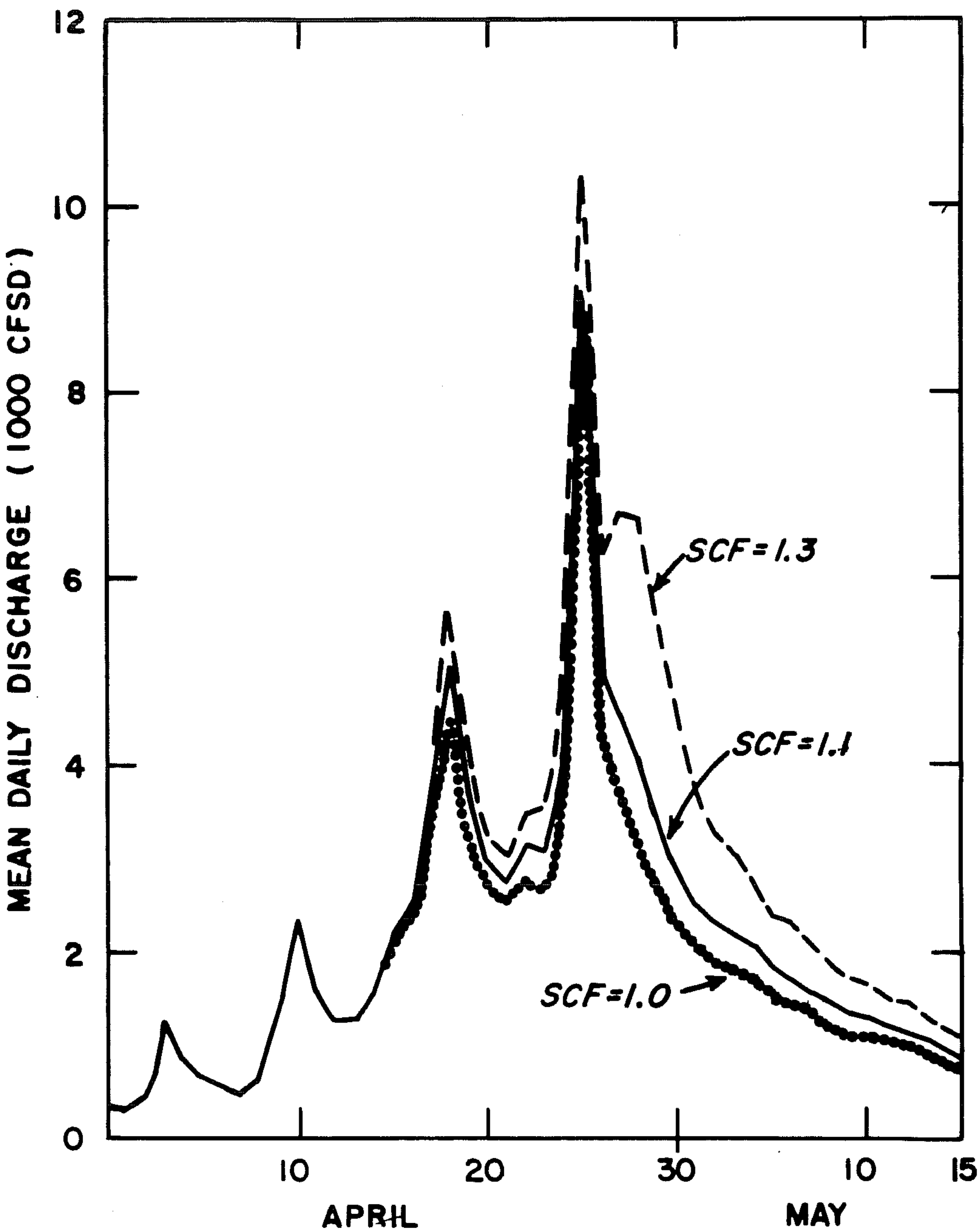

Figure 5-4. Effect of parameter SCF on spring snowmelt hydrograph. Passumpsic River at Passumpsic, Vermont, 1970.

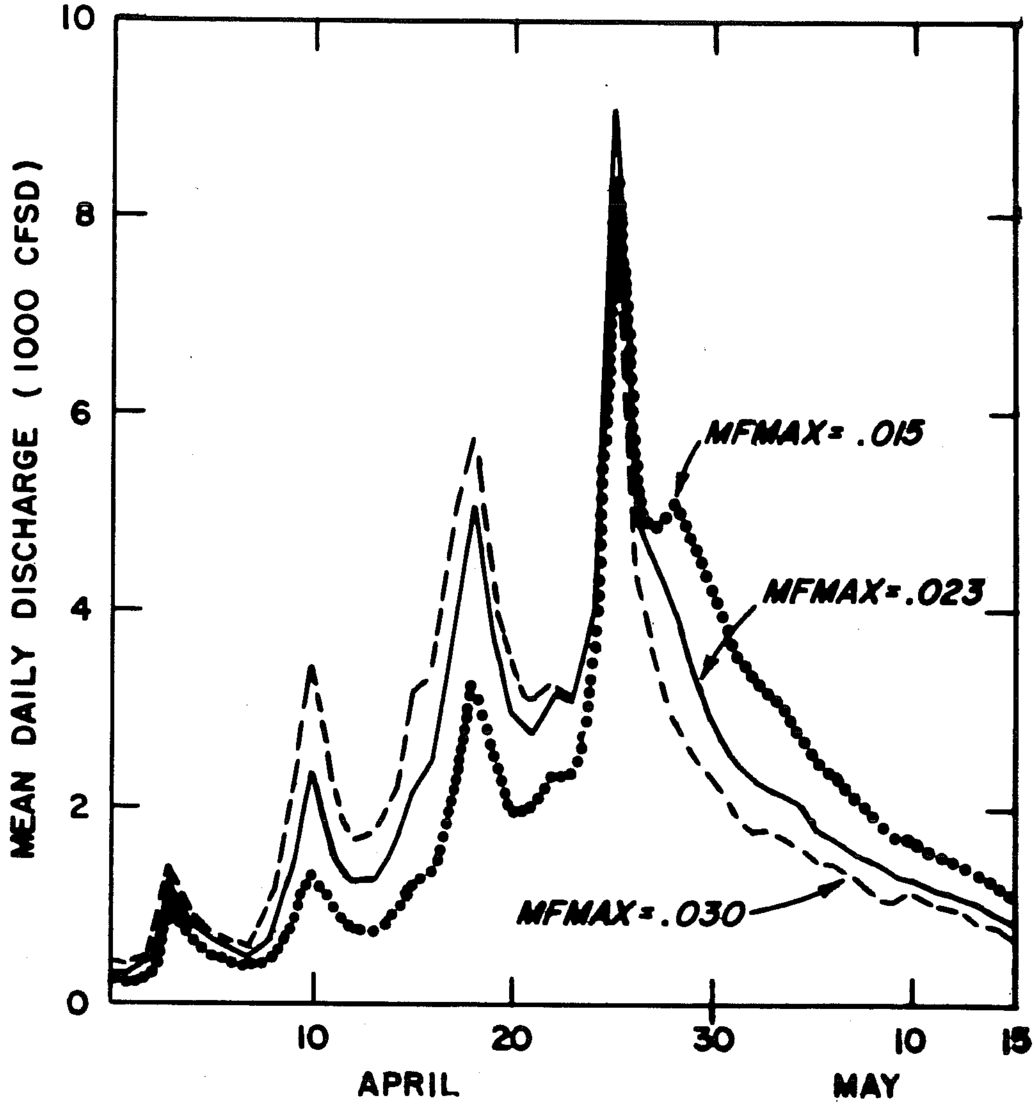

Figure 5-5. Effect of parameter MFMAX on spring snowmelt hydrograph. Passumpsic River at Passumpsic, Vermont, 1970.

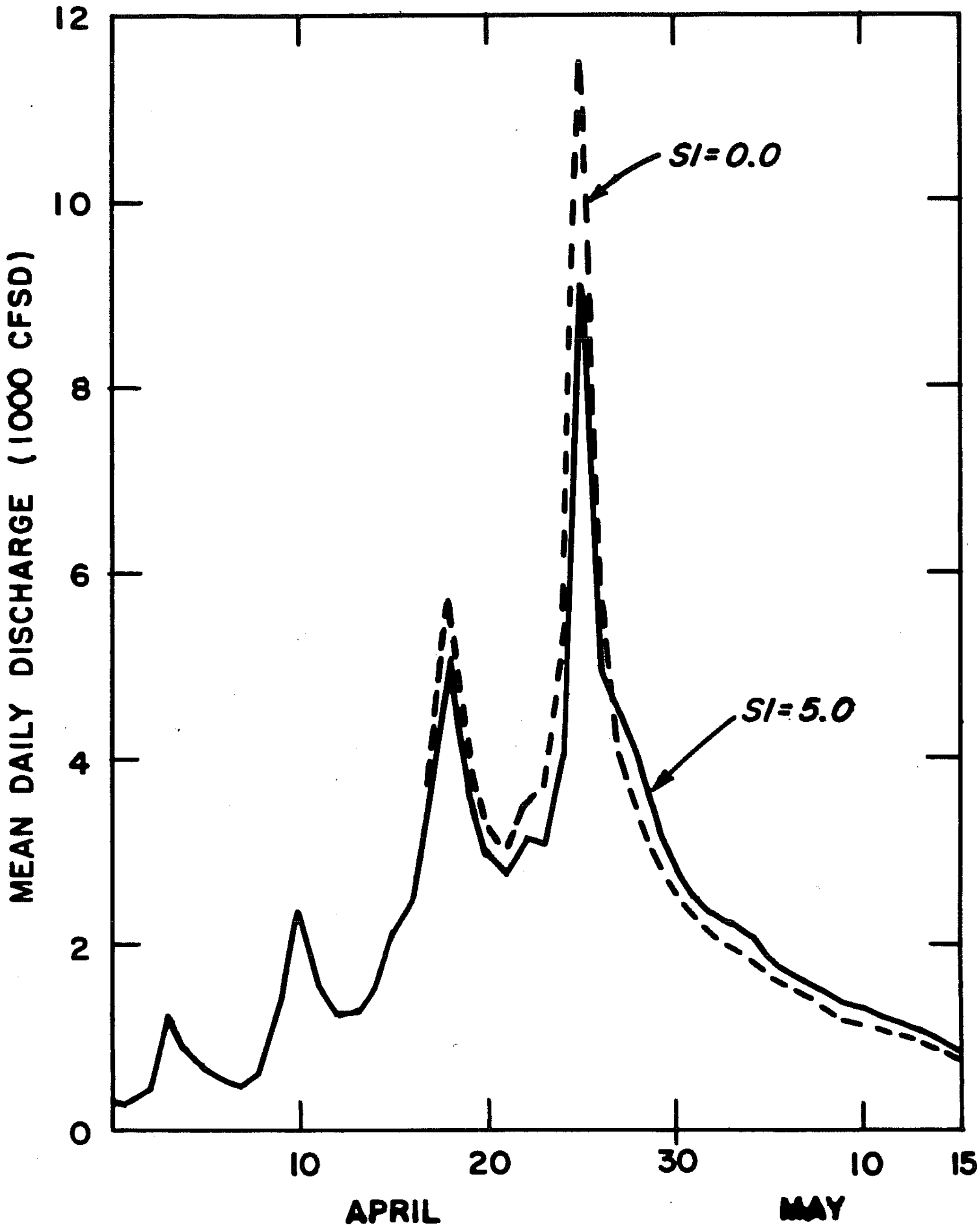

Figure 5-6. Effect of parameter SI on spring snowmelt hydrograph. Passumpsic River at Passumpsic, Vermont, 1970.

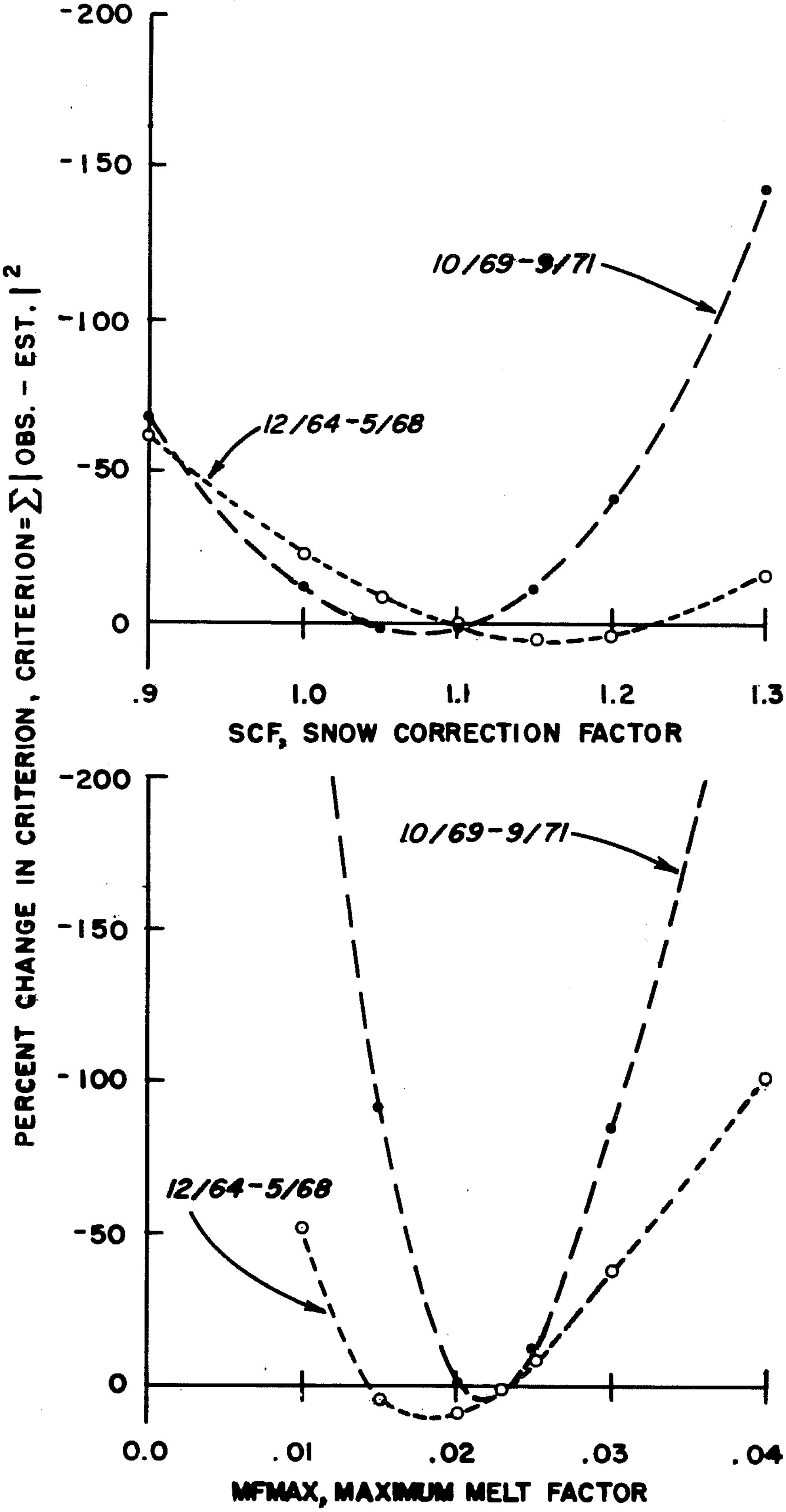

Figure 5-7. Sensitivity plots for parameters SCF and MFMAX. Passumpsic River at Passumpsic, Vermont, 1970.

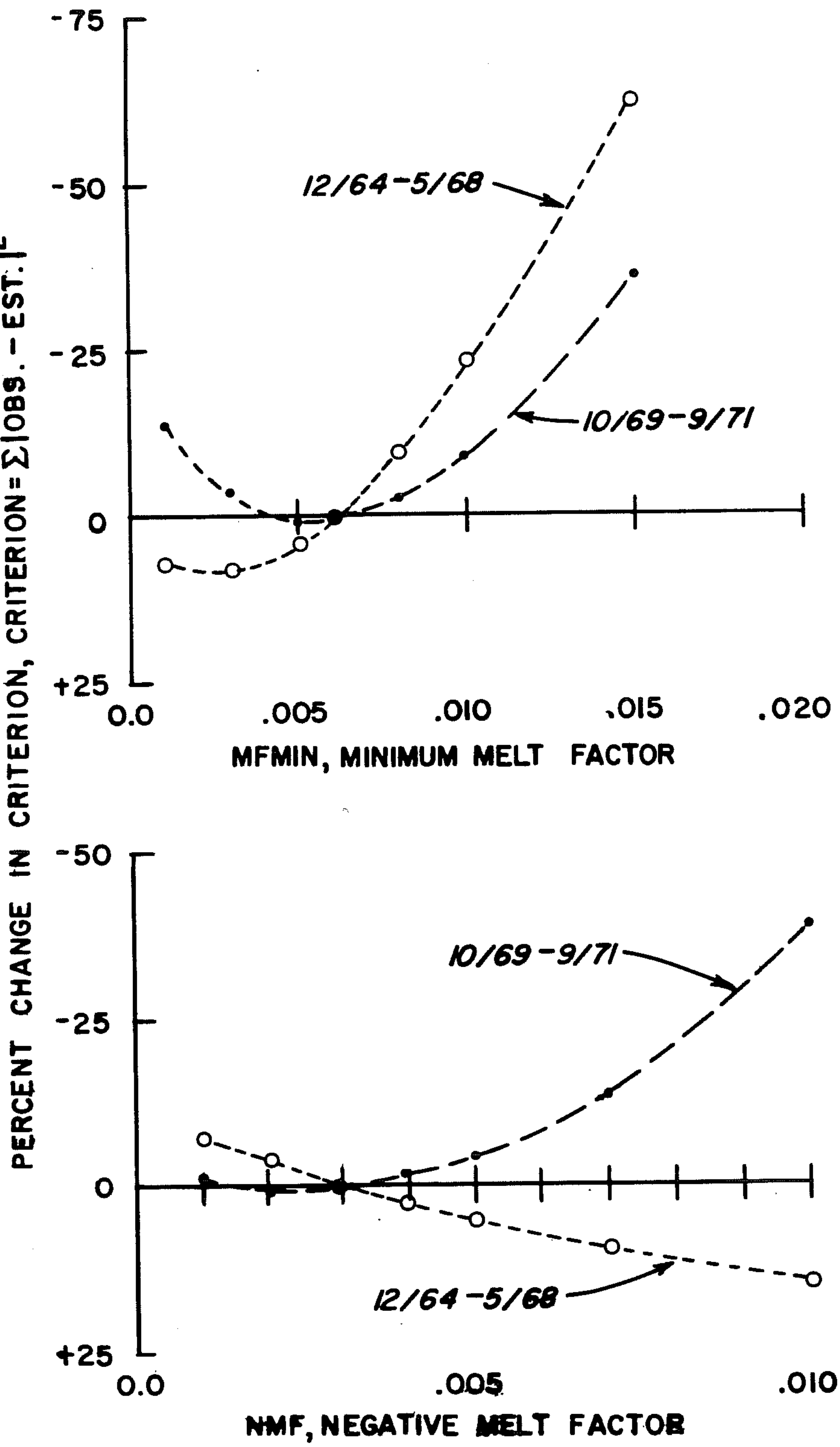

Figure 5-8. Sensitivity plots for parameters MFMIN and NMF. Passumpsic River at Passumpsic, Vermont, 1970.

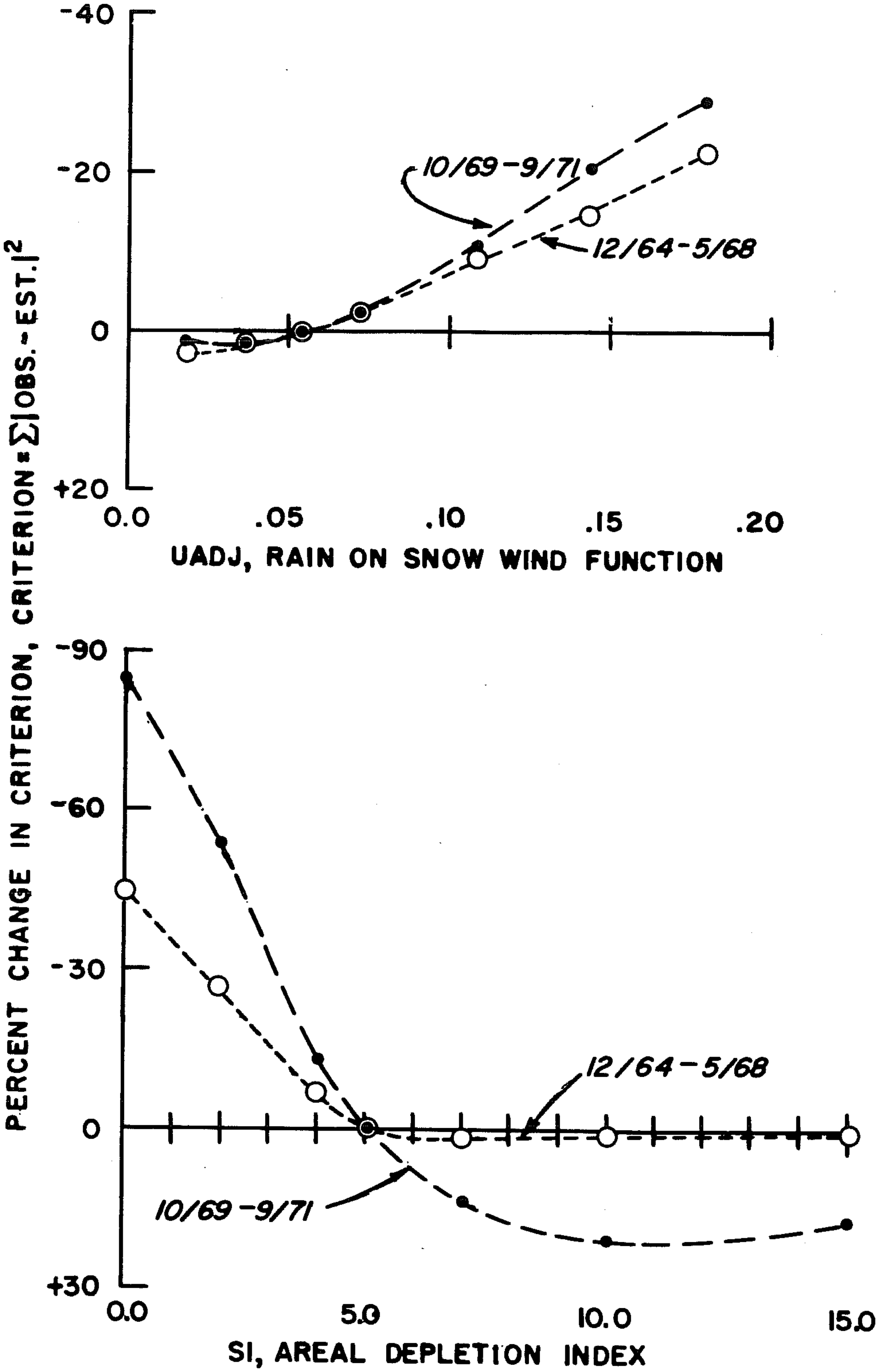

Figure 5-9. Sensitivity plots for parameters UADJ and SI. Passumpsic River at Passumpsic, Vermont, 1970.